$$\{\begin{bmatrix}1 & 1 & 1 & 1\\ 2 & 1 & -1 & -2\\ 1 & -1 & -1 & 1\\ 1 & -1 & 1 & -1\end{bmatrix}, \begin{bmatrix}1 & 1 & 1 & 1\\ 2 & 1 & -1 & -2\\ 1 & -1 & -1 & 1\\ 1 & -2 & 2 & -1\end{bmatrix}, \begin{bmatrix}1 & 1 & 1 & 1\\ 2 & 1 & -1 & -2\\ 1 & -1 & -1 & 1\\ 5 & -2 & 2 & -5\end{bmatrix}\}$$

REMARKS

The original 11 claims remain in this Reissue Application. Applicants have added Claims 12 through 23 to capture subject matter disclosed in the application that is more general than the original issued claims cover. As the remainder of these remarks will show, the newly claimed subject matter is disclosed in or is inherent in the existing specification.

At Col. 5, lines 4 through 22, the specification reads (in relevant part):

> It is well known that any M/2 x M/2 orthogonal matrix can be factorized into M(M-2)/8 plane rotations θ_i. . . . Any invertible matrix can be expressed as a sequence of pairwise plane rotations θ_i and scaling factors α_i as shown in Fig. 3. It is also well known that a plane rotation can be performed by 3 "shears":
>
> $$\begin{bmatrix}\cos\theta_i & -\sin\theta_i\\ \sin\theta_i & \cos\theta_i\end{bmatrix} = \begin{bmatrix}1 & \frac{\cos\theta_i - 1}{\sin\theta_i}\\ 0 & 1\end{bmatrix} \times \begin{bmatrix}1 & 0\\ \sin\theta_i & 1\end{bmatrix} \times \begin{bmatrix}1 & \frac{\cos\theta_i - 1}{\sin\theta_i}\\ 0 & 1\end{bmatrix}.$$
>
> This can easily be verified by computation.
>
> Each of the factors above is capable of being expressed as a "lifting" step in signal processing terminology.

Among the most important invertible transforms in applications are unitary transforms and biorthogonal transforms. The class of unitary (including orthogonal) transforms contains in particular the famous discrete cosine transform (DCT), the discrete Fourier transform

(DFT), the discrete sine transform (DST), the fast Fourier transform (FFT), and many other well known examples of transforms.

The invention of this Reissue Application incorporates a family of lapped unitary and biorthogonal transforms implementing a small number of dyadic-rational lifting steps. See Col. 2, lines 63 through 65. The class of lapped unitary and biorthogonal transforms is extremely broad, and in fact includes as a subset the unitary, orthogonal, and lapped orthogonal transforms. Previously in the art, lapped orthogonal transforms were known; see H. Malvar, *Signal Processing with Lapped Transforms*, Boston: Artech House, 1992. Here "lapped" refers to the transforms being (potentially) overlapped in their domain of action (in the initial transform case, sometimes the time domain, sometimes the length or space domain), which are more general than the ordinary block transforms, which may not overlap. The biorthogonal transforms disclosed in this invention are also more general than the orthogonal ones.

Thus the class of unitary and biorthogonal transforms is even more general than the class of orthogonal transforms and contains orthogonal transforms as a subset. See: P. Topiwala (ed.), *Wavelet Image and Video Compression*, Boston: Kluwer Academic Press, 1998. Finally, the class of lapped, biorthogonal transforms is yet more general, as lapped transforms are a superset of, that is, contains, ordinary block transforms.

The specification continues at Col. 5, lines 21 through 37: "Each of the factors above is capable of a "lifting" step in signal processing terminology. . . . The crossing arrangement of these flow paths is also referred to as a butterfly configuration. Each of the

above "shears" can be written as a lifting step. . . . In other words, we can replace each "rotation" by 3 closely related lifting steps with butterfly configuration."

Also according to the specification, Col. 6, lines 15 through 28:

> Here the free parameters [of lifting steps] can be chosen arbitrarily and independently without affecting perfect reconstruction. The inverses are trivially obtained by switching the order and the sign of the lifting steps. . . .
>
> . . . .
>
> Most importantly, fast-computable VLSI-friendly transforms are readily available when [the free parameters] are restricted to dyadic rational values, that is, rational fractions having (preferably small) powers of 2 denominators. With such coefficients, transform operations can for the most part be reduced to a small number of shifts and adds.

What this means is that the entire transform (and the inverse as well) takes place with no multiplication operations, in particular no floating point multiplications, so that the transform and the inverse is lightning fast compared with conventional versions of a particular transform.

What would be immediately apparent to one of ordinary skill in the art of signal processing and indeed, what is inherent in the disclosed invention, is that the DCT, FFT, and many other conventional transforms can be implemented in this way. Thus, for example, an integer approximation of the DCT can be implemented using a cascade of +/-1 butterflies and dyadic lifting steps. Furthermore, an inverse DCT can be easily realized using the same lifting steps in reverse order and inverted polarity (changing signs in all factors), cascaded with +/-1 butterflies.

In conventional (prior art) practice, implementation of the DCT involves use of rotation angles as shown in the left side of the equation at Col. 5, line 15. As shown in that equation, the invention of this specification utilizes a series of lifting steps instead. As disclosed in the specification, inverting a lifting step is achieved simply by inverting its polarity (the signs of all coefficients, as is well known in the art.

That this result is well within and inherent in the method of the specification of this reissue application, and therefore could be achieved by one of ordinary skill in the art, is shown by one of the references cited on the cover page of the '464 patent, Liang et al, ITU-Telecommunications Standardization Sector, "A 16-bit architecture for H.26L treating DCT transforms and quantization," pp. 1-12, May 29, 2001. Details of deriving approximate DCTs using the methods of the '464 patent were spelled out in this reference.

Thus in its most general form, the invention of the instant specification provides an M-channel perfect reconstruction block transform with linear phase filters that can be chosen to be multiplierless. The invention can be implemented through a cascade of +/-1 butterfly stages followed by a cascade of lifting steps and scaling factors. In particular, such a transform can map integer coefficients to integers with exact reconstruction.

As previously noted, all of the lifting coefficients can be chosen to be (dyadic) rational numbers. Each dyadic lifting step can be implemented by a simple combination of shift-and-add operations. This is in effect a multiplier-less approximate implementation of a broad class of unitary and biorthogonal transforms, which includes the DCT, the DST, the DFT, and many other well known transforms and their inverses that are very fast. In particular, this

approach produces approximations of the DCT which are fast to compute, made up of dyadic rational lifting steps and butterflies, which are multiplierless, produce perfect reconstruction, and have linear phase.

CONCLUSION

Applicants have made a diligent effort to place the added reissue claims in condition for allowance. However, should there remain unresolved issues that require adverse action, it is respectfully requested that the Examiner telephone the undersigned, Applicants' Attorney, at the telephone shown below so that such issues may be resolved as expeditiously as possible.

For these reasons, and in view of the above amendments, this application is now considered to be in condition for allowance and such action is earnestly solicited.

Respectfully submitted,

July 29, 2003
Date

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